PATENT

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Applicants:	Kelvin P. Self and Gerald A. Stangl	Att'y Dkt. No.:	082380-00541
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For:	SYSTEM AND METHOD FOR LOCATING AND TRACKING A BORING TOOL		

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PRELIMINARY AMENDMENT

In the specification:

A copy of the application as originally filed is forwarded herewith with paragraph numbering added pursuant to 37 C.F.R. 1.52(b)(6) for the Examiner's convenience. The amendments given below have been made using the copy of the application with the added paragraph numbering for ease of reference.

Please replace Paragraphs 18 through 19 with the following:

[0018] With continued reference to FIG. 1, the HDD system 10 comprises the drilling machine 22 operatively connected by the drill string 16 to a downhole tool assembly 24. The HDD system 10 further comprises the drill bit 18 or other directional boring tool, the downhole transmitters or beacons 26 and 28, and the tracking receiver 30. The progression of the borehole 12 along a desired path is facilitated by communication of information <u>33</u> between the tracking receiver 30 and controls 32 for the HDD system 10.

[0019] In operation, receiver 30 maybe positioned at one of a series of reference placement stations 34a through 34n on the ground surface in approximate parallel alignment with the intended path of borehole 12. Generally, receiver 30 is offset to one or the other side by the respective distances Xa through Xn. These distances may be substantially similar, for

instance within 5-10% of each other, though not required. Operation of the receiver 30 in conjunction with beacons 26 and 28[ ], as yet to be described, permits creation of a close-tolerance, on-grade borehole 12.

Please replace Paragraphs 21 through 22 with the following:

[0021] Referring still to FIG. 1, the drilling machine 22 comprises a frame 38, a carriage 40 movably supported on the frame, a spindle 42 (shown in FIG. 3) rotatably supported by the carriage, and a rotary drive system 20 operatively connected to the spindle. In the preferred embodiment, the drill string 16 is connected to the spindle 42 by way of a threaded connection, though other ways of connecting the drill string to the drilling machine 22 may be used. Advancement of the carriage 40 by way of an axial advancement means (not shown), and operation of the rotary drive system [24] 20 provide for advancement and rotation of the spindle 42 and, in turn, the drill string 16 and the directional boring tool 18 to create the borehole 12. Reactionary forces on the drilling machine 22 may be resisted by machine weight supplemented by earth anchors 46. As may be necessary at times, the directional boring tool 18 is disengaged from the earth at the distant end of borehole 12 by retraction of drill string 16 through reverse movement (to that described above) of the carriage 40 and rotary drive system 20.

[0022] Use of the drilling machine 22 in a traditional manner permits the directional boring tool 18 to be steered or guided along a desired path Generally, the present position and angular orientation of the directional boring tool 18 are determined using a tracking system such as the previously mentioned beacons 26, [and] 28 and walkover receiver 30 in a manner yet to be described. That information may be compared to the pre-planned desired path for the borehole 12 to determine whether a steering correction is necessary. If a steering correction is not needed, the directional boring tool 18 is advanced in a straight line by advancing and rotating the drill string 16. If a steering correction is required, the directional boring tool 18 is rotated to a proper heading (i.e., roll position). Change the direction of the borehole 12. The drill string 16 is then thrust forward by advancing carriage 40 without rotation by the rotary drive 20. The

directional boring tool 18 deflects off its previous course heading as the tool engages virgin soil beyond the point where rotational advance ceased. Steering response can be diminished – as may be necessary for example while drilling a curved section of the planned borepath - by periodically interjecting short "straight" (advance with rotation) drilling segments.

Please replace Paragraphs 25 through 30 with the following:

[0025] Turning now to FIG. 2, there is shown one of a plurality of dual-member pipe sections 52 comprising the dual-member drill string 16. The dual-member pipe section 52 comprises an outer member 54 and an inner member 56. Outer members 54 and inner member 56 of adjacent pipe sections, 52 are connected to form the dual-member drill string 16a <u>(FIG. 4).</u> Interconnected inner members 56 of adjacent dual-member pipe sections 52 are rotatable independently of the interconnected outer members 54. An annular space 58 between the inner members 56 and outer members 54, or a hollow tubular construction for inner member 56 (not illustrated), may be useful for conveyance of drilling fluid downhole for purposes later described. One or the other of these longitudinal cavities may also be useful for conveyance of slurried drill cuttings uphole for disposal. It will be appreciated that any dual-member drill string having an outer member and an inner member, the inner member disposed within the outer member and independently rotatable, may be used with the present invention. Embodiments for suitable dual member drill strings are described in U.S. Pat. No. 5,490,569 and U.S. Pat. No. 5,682,956, the contents of which are incorporated herein by reference.

[0026] Turning now to FIG. 3, a dual rotary drive system 44 is shown for use as the rotary drive system 20<u> (FIG. 1)</u>. The rotary drive system 44 has dual-spindles <u>42</u> for driving a dual-member drill string [18] <u>16</u>a. Rotary drive system 44 is slidably mounted on the frame 38 of drilling machine 22 <u>(FIG. 1)</u> by way of the carriage 40. The rotary drive system 44 comprises two independent drive groups 62 and 64 for independently driving the respective interconnected outer members 54 and interconnected inner members 56 comprising the dual-member drill string [18] <u>16</u>a. The outer members 54 and inner members 54 are thereby independently controllable of each other. For instance, as is advantageous with the present invention, outer

members 54 can be held without rotation while inner members 56 are rotated. A suitable dual-spindle rotary drive system 44 is disclosed in U.S. Pat. No. 5,682,956, which is incorporated herein by reference. As subsequently described, inner member drive group [64] 62, also called the inner member drive shaft group, may be adapted to rotationally drive directional boring tool 18.

[0027] With reference now to FIG. 4, shown therein is the downhole tool assembly 48 used with a dual-member drill string 16a to create borehole 12. Downhole tool assembly 48 comprises the two on-board transmitters or beacons 26_and 28. Data or information transmitted by the beacons 26_and 28 is received and processed, in a manner yet to be described, by receiver 30. Information processed by the receiver 30 may be relayed by wireless communications link 65 to the drilling machine 22, for determining , for example, if a steering correction is required. Alternately, use of the processed information may be accomplished within tracking receiver 30 and control signals 33 communicated to the drilling machine 22.

[0028] FIG. 5 shows the downhole tool assembly 48 of FIG. 4 in cross-sectional detail. For illustration proposes, side-entry chambers 66 and 68 shown at the 9 o'clock roll angle orientation in FIG. 4 have been moved to the 12 o'clock orientation in FIG. 5. In reference the downhole tool assembly 48 has a forward portion 70 comprising a forward housing assembly 72 and a [72] rear portion 74 comprising a bearing housing assembly 76[–]. The forward housing assembly 72 is preferably fixedly attached to the drill string 16a.[.] The round cross-section "forward" and "rearward" portions of downhole tool assembly 48 – excluding the slant-faced drill bit – may have a substantially uniform diameter, as so depicted. It should be understood, however, that equality of diameter between the forward and rearward portions of tool 48 is not required.

[0029] The directional boring tool 18 is represented herein by the flat-faced bit and a fluid dispensing nozzle. However, as previously mentioned, directional boring tool 18 may be any drilling device or bit which causes deviation of the tool from a straight path when thrust forward without rotation, or if thrust forward while repetitively rocking the drilling bit or boring

tool through an arc of partial rotation. The bit, mounted at an approximated 10-degree angle on the downhole end of forward housing assembly 72, is rotationally fixed to the inner member 56 of the drill string 16a by way of inner drive member 116 (indicated in FIG. 4 by its front portion). Thus the rotation of these components is through the control of inner member drive group 62.

[0030] Forward housing assembly 72 comprises the side-entry chamber 66 to accept the front transmitter or beacon 26, held therein by slotted retaining cover 78. It should be noted that housing assembly 72 could be configured for front-loading or end-loading of the front beacon 26. Preferably, the front beacon 26 is held in rotationally indexed relation to the orientation of directional boring tool 18 such that a roll sensor (not shown) disposed in the front beacon may correctly indicate the rotational orientation of directional boring tool 18. It will be appreciated that the front beacon 26 [way] may contain other sensors as deemed appropriate.

Please replace Paragraphs 32 through 40 with the following:

[0032] With continued reference to FIGS. 4 & 5, the bearing housing assembly 76 comprises [an] the inner drive member [78] 116 bearingly supported within a housing 80. The housing 80 comprises the side entry chamber 68. The rear beacon 28 is positioned in the chamber 68 and held therein by a slotted retaining cover [87] 81. The housing 80 further comprises an outer wall 82 that defines an interior bearing chamber 84. A rear end of the housing 80 is connectable to the outer member [56] 54 of the drill string 16a. Preferably, the housing 80 has male threading 85 for connection to a threaded female receiving connection 86 on the outer member [56] 54 of the drill string 16a. However, it should be understood that other torque transferring connections and configurations for the connections between the housing 80 and the drill string 16a are contemplated.

[0033] The bearingly supported inner drive member [78] 116 has a rear portion 88, a body 90, and a front portion 92. The front portion 92 is operatively connectable to the previously described forward housing assembly 72. In the preferred embodiment, the front portion 92 comprises a female threaded connection 93 for connection to a corresponding male threading 95

on the forward housing 72. The rear portion 88 extends out from the housing 80 and is connectable to the inner member 56 at the downhole end of the drill string 16a such that torque of the inner member is transferred to the inner drive member [78] 116. Preferably, the rear portion 88 of drive member [78] 116 comprises a geometrically shaped female connection 94 for sliding connection to a similarly shaped male connection on the inner member 56 of the drill string 16a. Other torque transferring connections and configurations for the connections between the inner drive member [78] 116 and the drill string 16a are also contemplated.

[0034] The body 90 of the inner drive member [78] 116 is supported within the bearing chamber 84 of the housing 80 by a bearing arrangement 96. Preferably, the bearings 96 are sealed and position the inner drive member [78] 116 generally coaxially within the housing 80. However, some lateral offset or non-symmetrical outer diameter for housing 80 is permissible to accommodate beacon 28 therein. In the preferred embodiment, seals 98, wear rings 100, and seal gland[s] 102 are positioned to retain the bearings 96 in position around the body 90. Preferably, the sealed bearings 96 are periodically lubricated via a pluggable point of access (not shown). This arrangement prevents slurried drill cuttings from reaching and damaging the bearings 96.

[0035] One skilled in the art will appreciate the use of drilling fluids during horizontal directional drilling for purposes such as cooling the directional boring tool 18 and the beacons 26 and 28, and to stabilize the borehole. Preferably, the inner drive member [78] 116 comprises at least one fluid passage 104 for communicating drilling fluid from the annular space 58 (shown in FIG. 2) between the inner member 56 and the outer member 54 of the drill string 16a through the downhole tool assembly 48 for discharge through a nozzle 106 at a front end of the forward housing assembly 72. The fluid passage 104 preferably passes in proximity to beacons 26 and 28 prior to reaching nozzle 106.

[0036] With reference to FIGS. 4 and 5, directional boring tool 18 and forward housing assembly 72 are rotatable by the inner member 56 of the dual-member drill string 16a independently of the bearing housing assembly 76, the latter being held without rotation or being separately rotatable by the outer member 54 of the dual-member drill string. As the inner

member 56 of the drill string 16a is rotated, the change in rotational orientation of the boring tool 18 can be detected by the roll sensor of front beacon 26. This information may be transmitted to the above-ground tracking receiver 30, where it can be further processed, displayed to the receiver operator, and relayed by wireless communications link [448] 65 or other means to the operator and/or automated control system of the drilling machine 22[,].

[0037] With reference now to FIGs. 6 and 7, shown therein is a ~~an alternate embodiment of the~~ downhole tool assembly 50 for use with a single-member drill string 16b. The downhole tool assembly 50 comprises a forward housing assembly 108 and is substantially identical to that of the assembly 72 in the previously described embodiment of FIGs. 4 and 5. Similarly as in that embodiment, a side-entry chamber 110 – shown in 9 o'clock roll angle orientation in FIG. 6 – has been moved to the 12 o'clock orientation in FIG. 7. The downhole tool assembly 50 further comprises a bearing housing assembly 112 at a rear portion of the tool assembly. The bearing housing assembly 112 is adapted for attachment to the downhole end of the single-member drill string 16b.

[0038] The bearing housing assembly 112, shown in greater detail in FIG. 7, comprises a bearing housing [113] 114 with a straight central axis and an inner drive member 116. The inner drive member 116 is bearingly supported and passes through bearing housing 114.

[0039] The inner drive member 116 has a rear portion 118, a body 120, and a front portion 122. Preferably, the inner drive member 116 comprises at least one fluid passage 124 for communicating drilling fluid from the interior of single-member drill string 16b through the downhole tool assembly 50 for discharge through a nozzle 126 at a front end of the forward housing assembly 108. The front portion 122 of the inner drive member 116 is operatively connectable to the forward housing assembly 108. Although other forms of construction are contemplated, in the preferred embodiment the front portion 122 comprises a female threaded connection. The inner drive member 116 is connectable to the downhole end of the single-member drill string 16b.

[0040] As shown in FIG. 7, the bearing housing assembly 112 is held in axial assembly by roll pin 128 engaging the body portion 120 of inner drive member 116 to the rear portion 118. Mating splines (not shown) are contemplated for torque transferal between the body portion 120 of inner drive member 116 and rear portion 118 [or] <u>of</u> the inner drive member 116.

Please replace Paragraph 42 with the following:

[0042] Bearing housing 114 defines an outer wall 132 and an interior bearing chamber 134. The body 120 of the inner drive member 116 is supported within the bearing chamber 134 by [a] bearing arrangement [136] <u>130</u>. Preferably, bearings [136] <u>130</u> are sealed and position the inner drive member 116 generally coaxially within the housing 114. However, some lateral offset or non-symmetrical outer diameter for housing 114 is permissible to accommodate the beacon 28 therein. In the preferred embodiment, seals 138, wear rings (not shown), seal glands 140, and thrust washers 142 are positioned to retain the bearings [136] <u>130</u> in position within housing 114 and around the body 120 of inner drive member 116. Preferably, the sealed bearings 136 are periodically lubricated via a pluggable point of access (not shown). This arrangement prevents slurried drill cuttings from reaching and damaging the bearings 136.

Please replace Paragraphs 46 through 49 with the following:

[0046] The position and orientation sensing system comprised of beacons 26 and 28 and walkover receiver 30 (FIG. 1) will now be described in greater detail. From the embodiment descriptions herein, it should be apparent that whenever the directional boring tool 18 is rotated to drill a straight segment of the borehole 12, the front beacon 26 and sensors therein for measuring one or more of the angular orientations of forward housing ~~assembly~~ assemblies 72 and 108 also rotate. Rotation can detrimentally affect pitch sensor readings, which are critical for on-grade applications. Also, yaw orientational outputs are generally unavailable at drilling rotational speeds. Placement of such sensors in a non-rotating rear beacon 28 of the present invention overcomes the need for the rotational advance of directional boring tool 18 to be stopped frequently to verify that it has not been deviated up-down and/or left-right off a straight path line by such effects as gravity, the tendency of a rotating bit to "walk", or variations in soil conditions. The monitoring of pitch and, if so desired, yaw headings throughout the creation of the borehole 12 offers substantial productivity improvement. Constancy of the pitch and yaw angular heading components gives assurance that a straight path is being maintained, within the constraints of sensor measurement system accuracy.

[0047] For the embodiments of FIGS. 4-9, as indicated previously, beacons 26 and 28 may comprise one or more sensors for measuring information representative of one or more of three angular orientations: roll, pitch and yaw of the respective forward and rearward portions of downhole tool ~~assembly~~ assemblies 48 or 50. Specifically, the front beacon 26 may sense at least the roll orientation angle of directional boring tool 18. The rear beacon 28 can sense at least the pitch orientation angle of the rearward portion of the downhole tool ~~assembly~~ assemblies 48 or 50 and, as may be desired, also its yaw orientation. It should be understood, however, that this does not preclude inclusion of a roll sensor in rear beacon 28 – as may be required to properly orient some types of yaw sensors. Additional sensors may also be included within beacons 26 and 28. Sensors for orientation determination may comprise a variety of devices, including:

inclinometers, accelerometers, and gyroscopes. This information is attached onto the respective signals transmitted by the beacons 26 and 28 to the above-ground tracking receiver 30_by means of various known communication schemes. Beacons 26 and 28 and the tracking receiver 30 preferably constitute an improved, yet to be described position and orientation sensing system. However, a basic walkover style position and orientation sensing system could also be utilized. Such systems are described in U.S. Pat. No. 5,264,795 issued to Rider, U.S. Pat. No. 5,850,624 issued to Gard, et. al., and U.S. Pat. No. 5,880,680 issued to Wisehart, et. al., the contents of which are incorporated herein by reference. Orientation sensors for determining the roll (a.k.a. tool face), pitch (a.k.a. inclination and grade), and/or yaw (a.k.a. left-right heading and azimuth) angular coordinates comprising the vector heading of the drill head are described in the latter two patents as well as in U.S. Pat. Nos. 5,133,417 and 5,174,033 issued to Rider and U.S. Pat. No. 5,703,484 issued to Bieberdorf, et. al., the contents of which are also incorporated herein by reference.

[0048] As used herein, it should be understood that the sensors of beacons 26 and 28 provide the above-mentioned angular information with sufficient accuracy for drilling close-tolerance boreholes. As with front beacon 26 and its housing 72 or 108, the rear beacon 28 is held in rotationally indexed relation to the orientation of housing 80 or 114 to insure there is no shift in rotational relationship during drilling. Preferably, beacons 26 and 28 and their internal sensors are maintained in parallel axial alignment with respect to the central axis of downhole tool ~~assembly~~ assemblies 48 or 50. Not withstanding that preference, one skilled in the art can appreciate that residual non-parallelism can be removed through system calibration and electronic compensation after placement in their respective chambers. It can also be appreciated that, although not so depicted in FIGS. 4-9, some radial protrusion of chambers 66, 68 and [134] 110 and slotted covers 78, 81 and [150] 148 will not detrimentally detract from the performance of downhole tool assemblies 48 or 50.

[0049] One skilled in the art will appreciate that other types of position and orientation sensing systems – such as "remote" (non walkover) systems – would also be suitable for use with one or more drilling systems described herein. Alternately, a wireline or other drill string communication system could carry certain information from beacons 26 and 28 back to the drilling machine 22 instead of the wireless communications link [448] <u>65</u> illustrated in FIGS. 1 and 4.

Please replace Paragraph 53 with the following:

[0053] As stated earlier, rear beacon 28 of the present invention is held without rotation by outer drill string member 54 or, for the single-member drill string embodiments, by the stabilizing features 144 or 146 of housing [80] <u>114</u> or 114<u>a</u>. This offers substantial productivity improvement by allowing pitch – and, when the sensor is included, yaw – headings to be monitored throughout the creation of the borehole 12. This is particularly advantageous while drilling a straight path segment of the borehole 12 wherein to maintain the present heading, forward housing assembly 72 or 108 is rotated while carriage 40 is advanced. Thus any heading sensors within front beacon 26 are subjected to the previously described effects of rotation, whereas those in rear beacon 28 are not. Tracking receiver 30 may now utilize the signal transmissions of rear beacon 28 to process, display, and relay heading and/or positional information for MWD determination whether or not a straight path is being maintained. This enables "on the fly" decision-making control of the HDD system 10 by its operator or by its automated control system.

Please replace Paragraph 56 with the following:

[0056] Turning now to FIG. 10, shown therein is a tracking receiver 30 having the ability to monitor the position and orientation of the beacons 26 and 28 within the operating area of the HDD system 10. Positional information (i.e., location and depth) along with pitch heading (and yaw, if desired) is manually or automatically compared to the desired path for the borehole 12,

thereby determining any need of directional change in the next interval to be drilled. In general, receiver 30 may be comprised of a plurality of magnetic field sensors 150 an 152, appropriate electronics (not shown) for the amplification and filtering for the outputs of each magnetic field sensor, a multiplexer (not shown), an A/D converter (not shown), processor (not shown), a display 154, wireless communications link [448] <u>65</u>, batteries (not shown), software/firmware, and other items necessary for system operation, as well as useful accessories (not shown) such as a geographical positioning system.